The reproductive cycle of the Asian House Gecko (*Hemidactylus frenatus*) in Brisbane, south-eastern Queensland: a tropical invader of a subtropical, seasonal environment.

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ABSTRACT

The Asian House Gecko, *Hemidactylus frenatus*, is a successful invader of much of the tropical habitat of the world. It has also colonised many subtropical, seasonal areas, including Brisbane, Queensland, where it has become abundant, further from the equator than any other known breeding population. The reproductive cycle of this population was investigated and, in contrast to equatorial populations, it was found to be strongly seasonal, with females generally ceasing breeding activity in March to August and males also reducing reproductive effort May to June. ❒ *Asian House Gecko, Hemidactylus frenatus, invasive species, Queensland.*

The biology of invasive species is an increasingly urgent topic of research as more and more species successfully colonise new areas with human assistance, deliberate or otherwise. A relatively small number of animal and plant species are spreading throughout large parts of the globe. The effects of the new settlers can be dramatic, such as the smothering of all other plants by rubber vine (*Cryptostegia grandiflora*) or more subtle, but all tend towards the reduction of the distinctiveness of disparate ecosystems, a process that has been styled as "McDonaldisation" of the world's biodiversity (Holmes 1998; Lövei 1997; Low 2001). A better understanding of the factors permitting invasive species to reproduce and adapt successfully to new environments is crucial to either reducing the impact or, more hopefully, preventing invasions.

The Asian House Gecko, *Hemidactylus frenatus* Duméril and Bibron, 1836, is one such invader. Its original distribution is uncertain but thought to centre on south-east Asia, from India to Indonesia (Case *et al.* 1994). It has now spread in a broad band around the equator, being known from central America to the islands of the Indian and Pacific Oceans (Case *et al.* 1994; Cole 2005; Rödder *et al.* 2008). It was first recorded in Australia at Port Essington, Northern Territory, in the 1840s. This colony was thought to have died out when humans abandoned this early settlement (Cogger & Lindner 1974) but the species was re-collected on Coburg Peninsula in 1990 (Fisher & Calaby 2009). The species' next appearance was in Darwin in the 1960s where they have since become abundant and have spread into native bushland outside the city (Cook 1990; Covacevich *et al.* 2001; Keim 2002; Newbery & Jones 2007). Asian House Geckos were first recorded in Brisbane in 1983 when specimens from the wharves were donated to the Queensland Museum (Covacevich *et al.* 2001). They are now one of the commonest reptiles to be encountered in this city, being found in abundance on buildings from the inner city to the outer suburbs and outlying towns. This spectacular success is all the more intriguing given that the

Brisbane population is the furthest from the equator known to be reproductively successful. In Java (6° S from the equator and within its presumptive native range), *H. frenatus* is a continuous breeder, with no apparent seasonal pattern in males or females (Church 1962). This strategy is understandable in an equatorial climate, where there is little temperature or humidity change through the year. However, *H. frenatus* has now spread to more subtropical parts of the world which are distinctly seasonal and where year-round reproduction would seem to be disadvantageous. Populations living in the Ryukyu Islands (politically part of Japan, 25° 57′ N) and Taiwan (24° 10′ N) are strongly seasonal with reproductive activity confined to the spring and summer months (Cheng 1988; Cheng & Lin 1977; Lin & Cheng 1984; Ota 1994). However, females in a Mexican population (19° 30′ N) are reported to be aseasonal (Ramírez-Bautista *et al.* 2006).

Hemidactylus frenatus has been in Taiwan and the Ryukyus for a considerable time (a synonym of *H. frenatus*, *H. inornatus* Hallowell, was described from the Ryukyus in 1861) and some adaptation to the environment would be expected. The species has been present in Brisbane for a much shorter time frame and Brisbane is further from the equator than any other breeding population (27 ° 28′ S). In order to better understand why *H. frenatus* has been so successful in such a different environment to that of its native range, the annual reproductive cycle of the Brisbane population was examined to determine whether it remains aseasonal like its tropical ancestral population, has become strongly seasonal like established Northern Hemisphere subtropical populations or is somewhere in between.

METHODS

The population of *Hemidactylus frenatus* from south-eastern Queensland was sampled by hand collecting specimens from sites around suburban Brisbane (between 27° 20′ S and 27° 31′ S) monthly between October 2009 and September 2010. On capture, specimens were euthanased, preserved and accessioned into the collection of the Queensland Museum. Geckos were handled following procedures approved by the Queensland Museum Ethics Committee (permit no. 09-02). Additional specimens were donated by the public to the Queensland Museum.

Snout-vent length (SVL) of specimens was measured with Mitutoyo electronic callipers. A small abdominal incision was made to allow determination of gender. If male, the epididymis was classed as Not Visible, Visible or Full. If female, the width of the largest ovarian follicle was measured and the ovary was classed as Non-vitellogenic (all follicles small and white), Vitellogenic (an enlarged, yellow follicle present) or Gravid (ovulated ovum present in the oviduct). If gravid, the width of the ovulated ovum and the largest ovarian follicle were both measured. Previous workers have classed a specimen as fecund if they had yolked ovarian follicles of 2 mm (Cheng 1988), 2.5 mm (Lin & Cheng 1984) or 3 mm (Church 1962). However, the smallest yolked follicle in this study was found to be 1.47 mm in diameter, so it was decided to use follicle colour (yellow rather than white) rather than size as the determinant of reproductive condition.

Specimens smaller than the smallest individual found to be reproductively active in each sex were classed as immature. The assumption was made that individuals larger than this with no reproductive activity were non-reproductive, rather than immature.

Uncertainty regarding size at sexual maturity at time of collection meant that a proportion of captures turned out to be sexually immature. Unfortunately, this impacted sample size significantly, so that lower numbers of mature individuals than hoped were collected, and no mature females were collected in January and no mature males in March. Therefore months were combined for statistical analysis (Dec-Jan, Feb-Mar, Apr-May, Jun-Jul, Aug-Sep, Oct-Nov). The data were analysed using Excel and Systat 11.

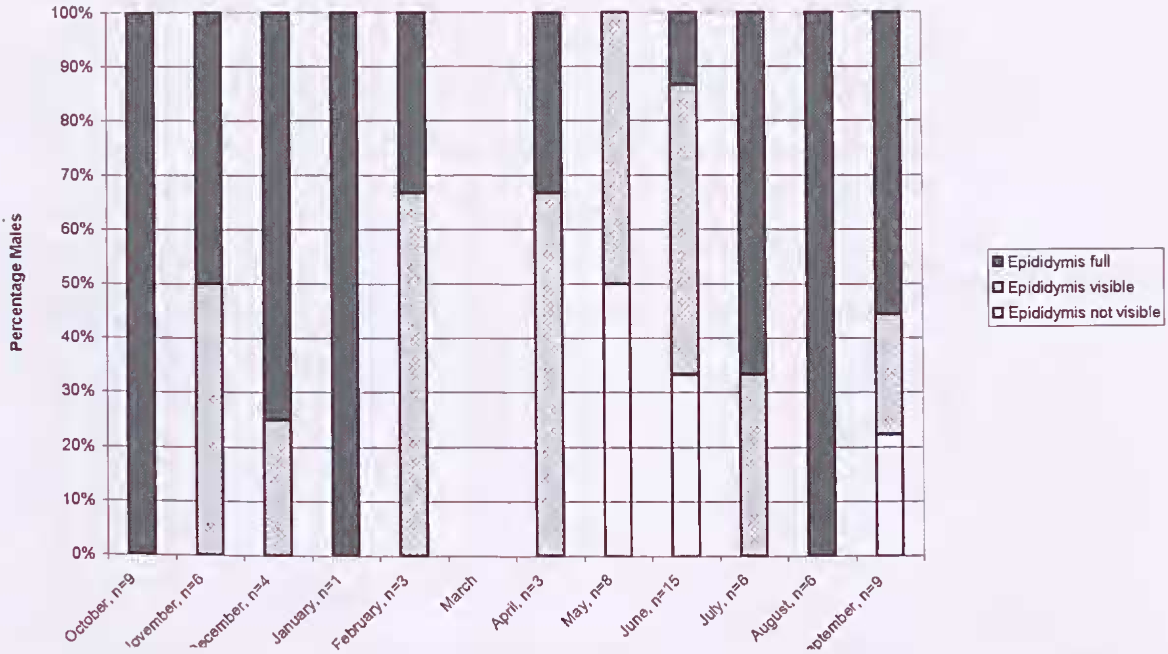

FIG. 1. Reproductive activity of female *Hemidactylus frenatus* in Brisbane between October 2009 and September 2010.

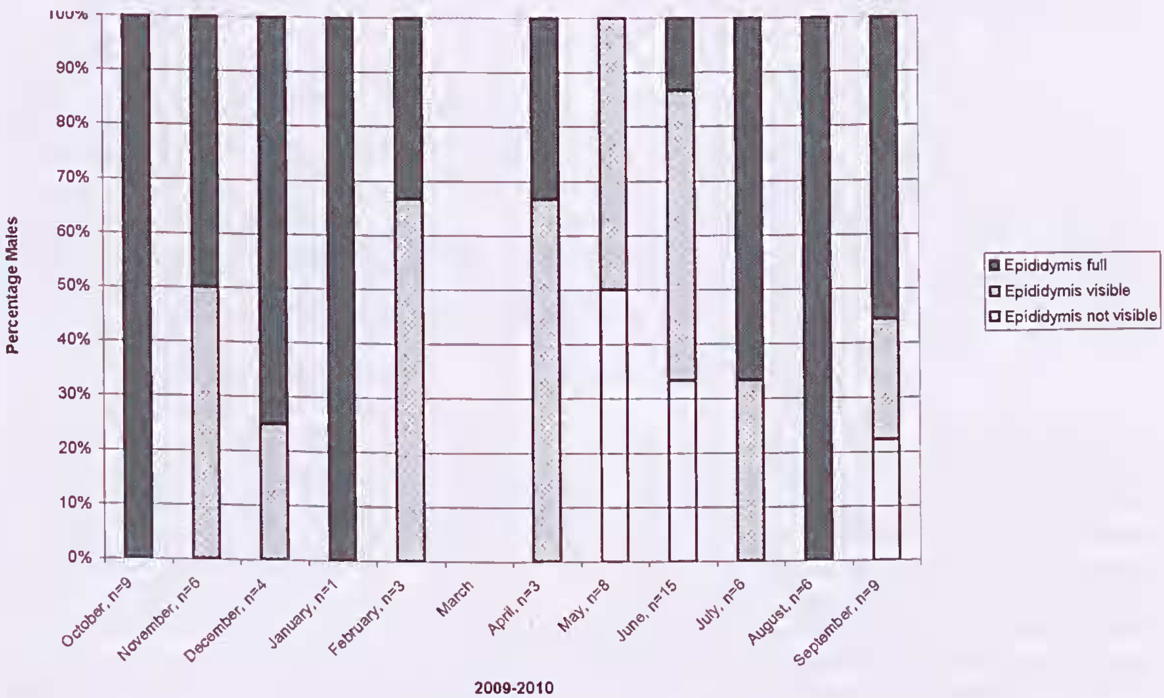

FIG. 2. Reproductive activity of male *Hemidactylus frenatus* in Brisbane between October 2009 and September 2010.

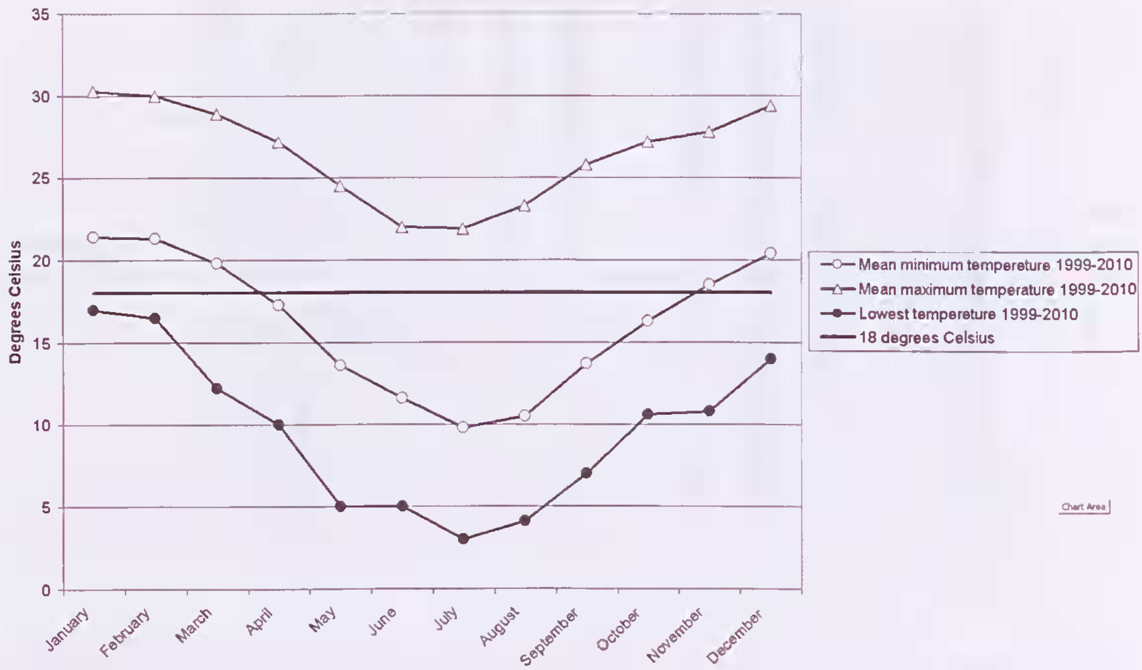

FIG. 3. Temperature ranges recorded in Brisbane between 1999 and 2010. Data from Australian Bureau of Meteorology website Climate Data Online (http://www.bom.gov.au/climate/data, accessed 26 July 2010).

RESULTS

A significant size difference between the sexes was observed (t-test, t = -3.535, df = 112, p = 0.001). Mature males averaged 55.05 mm snout-vent length (SE = 0.52, n = 59) while females averaged 51.03 mm (SE = 0.36, n = 45). The largest specimen collected in this study (62.72 mm) was male, whereas the largest female was 57.42 mm. The smallest vitellogenic female was 44.58 mm SVL while the smallest male with a visible epididymis was 42.10 mm SVL.

Females were clearly reproductively seasonal. Months differed significantly in numbers of reproductive females (vitellogenic and gravid combined; χ^2 = 33.945, df = 5, p = 0.000) with markedly reduced reproductive activity around April when no vitellogenic or gravid individuals were collected (Fig. 1). Some reproductive activity was seen June to August, but it was not until September that the majority of females were reproductively active. Gravid females were not vitellogenic in any month.

Males showed a less pronounced peak in reproductive activity (Fig. 2) with little significant difference between months in number of reproductive males (epididymis Visible or Full classes combined; χ^2 = 7.615, df = 5, p = 0.179). Males with turgid testes and enlarged epididymides were observed in all months except May but reproductive activity seemed somewhat reduced May to June.

DISCUSSION

The reproductive cycle of *H. frenatus* in Brisbane, the furthest population from the equator known to be reproducing successfully, is similar to that of populations in Taiwan and the Ryukyu islands, where breeding is strongly seasonal (Cheng 1988; Cheng & Lin 1977; Lin & Cheng 1984; Ota 1994), rather than that of Java, where breeding occurs year round (Church 1962). The selective pressure to reduce breeding effort in the cooler months is understandable given the temperature sensitivity of *H. frenatus*. Metabolism of this species is impaired below 26° C and eggs die if they are exposed to temperatures below 18°C, according to studies carried out on populations in Brunei (Snyder & Weathers 1976) and the Ryukyus (Ota 1994) respectively. Figure 3 shows that air temperatures lower than 18° C are possible at any time of year in Brisbane, but are to be expected April-October. Although egg temperature is likely to more closely follow substrate, rather than air, temperature, this still suggests that keeping eggs consistently warm enough is likely to be challenging during a Brisbane winter. The oviposition site selected by the female no doubt has a large role in buffering environmental variation and protecting the eggs from extremes of temperature, especially in human-modified environments where lights, water heaters and other powered devices can provide heat. Such heat sources are unavailable in more natural environments, which could preclude successful incubation. This may be a factor limiting the expansion of *H. frenatus* into the bushland surrounding Brisbane. While this species is known to have colonised natural environments around Darwin in the Northern Territory (Keim 2002), no such observations have been made in Brisbane. However, it must be borne in mind that the Darwin population has been in existence for considerably longer than that in Brisbane and eventual adaptation and invasion of Brisbane's natural environment cannot be ruled out.

Data presented in this paper show that females are not simply suspending vitellogenesis in response to lower temperatures and resuming once conditions improve. If this were the case, suspended but vitellogenic follicles should have been observed in the winter months. This observation suggests an adaptive response anticipating the cooler temperatures of winter. A cessation of reproduction as winter approached was also observed in Taiwan, well before food availability, a potentially limiting factor, declined (Lin & Cheng 1984).

While size at maturity for females in Brisbane is the same as in Taiwan (Lin & Cheng 1984), an interesting difference between the Brisbane population and other subtropical populations is the apparent lower reproductive effort of *H. frenatus* living in Brisbane. 100% of females in Taiwan were reproductive in June (n = 23) and many gravid females were also vitellogenic, that is, the next clutch was already developing (Lin & Cheng 1984). A maximum of 75% of Brisbane females were vitellogenic or gravid at any one time and none were both. Whether this is a consequence of poorer adaptation to Brisbane conditions or an acute response to the conditions of 2009-2010, when Brisbane was experiencing a severe drought, cannot be determined from the present data.

The cooler temperatures experienced in the middle of the year also appear to affect male reproductive activity, but males do not show as strong a response as females. While a reduction in reproductive effort is discernible May-June, some reproductive activity was observed year round. Although spermatogenesis was not assessed in this study, it is likely that males in Brisbane are behaving similarly to those in Taiwan, which were defined as 'confined acyclic' because, although testis weight varied seasonally, spermatogenic activity was constant (Chen *et al.* 1987; Cheng 1988). This is in keeping with ideas of male reproductive strategy, where the cost of maintaining spermatogenic activity is small enough to be compensated for by the reduced chances of securing a successful mating outside the normal breeding period (Wilhoft 1963). This is especially the case in species where females are capable of storing sperm, which has been documented in *H. frenatus* (Murphy-Walker & Haley 1996; Yamamoto & Ota 2006). In support of this, a mating pair was observed during collection of specimens in the Brisbane winter (8 June 2010).

There are three possibilities to explain the adaptation of *H. frenatus* to Brisbane conditions. Firstly, selection could have acted on acyclic founders to create a cyclic population. Secondly, the founding population could be derived from cyclic populations, such as those in Taiwan. It certainly seems likely that Taiwan has supplied a significant proportion of the geckos that have invaded Brisbane, given the volume of shipping traffic between the two. Even in a mix of founders from cyclic and acyclic populations, those from cyclic populations would be expected to outcompete those less well-adapted. The third possibility is that individual *Hemidactylus frenatus* are capable of adjusting their reproductive activity to the environment they find themselves in. This 'facultatively cyclic' hypothesis was favoured by Lin and Cheng (1984). Such adaptability may be a critical factor in the invasive success of this gecko. This idea could be tested by taking specimens from a population and subjecting them to conditions different from their usual experience (for example, Brisbane geckos in a constant temperature and humidity environment) and observing whether they adjust their reproductive behaviour accordingly.

In summary, the invasive success of the tropical, aseasonally breeding gecko *Hemidactylus frenatus* into different climates such as that of Brisbane can be partly attributed to its ability to readily become a seasonal breeder by reducing breeding activity in the cooler months. This effect is more marked in females than males, presumably because of sperm storage by females.

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